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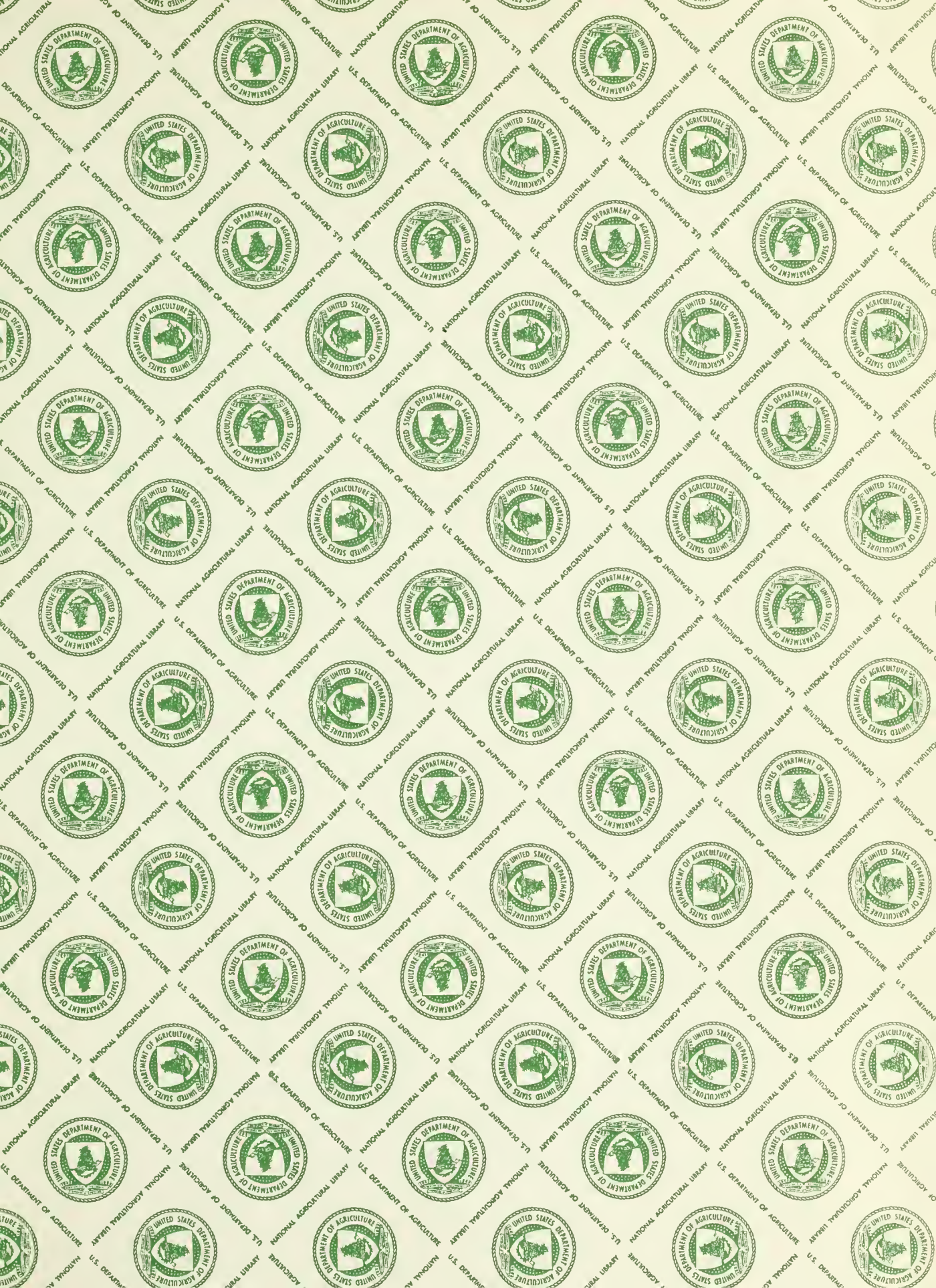
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Straw for Industrial Use, Collection Problems and Quality*

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Abstract

The suitability, availability, and geographical location of cereal straws for industrial use are discussed. Physical and chemical analyses of the various parts of wheat straw showed that the less valuable portions of the straw from the standpoint of pulping are the chaff, the heads, and the leaf blades, while the most valuable portions are the stems. Different varieties of straw vary considerably in the proportion of stems to chaff, heads, and leaf blades. Physical and chemical examination of combine-harvested straw and stubble after 35 days' weathering in the field showed practically no loss in valuable constituents for pulping purposes.

Present-day methods of harvesting and collecting straw are described and their costs and economics in comparison with those of older methods of using farm stack straw are discussed. It is shown that on a $6.00 delivered price for farm stack straw about $1.00 of the cost is represented by the chaff. Chaff is almost entirely eliminated by the use of combine-harvested straw and the use of such straw should, therefore, bring about a saving in pulping operations. Recent improvements in harvesting methods and equipment, including pick-up balers, indicate possible savings of approximately $1.00 per ton in straw collection. Based on the use of straw of lower chaff content, lower collection costs due to better methods, and decrease in transportation costs, a scheme is suggested that will enable both the farmer and the pulp mill operator to receive benefits of approximately $1.50 each per ton of straw and still maintain the price of delivered straw at $6.00 per ton.

Numerous questions have arisen regarding the use of straw as a raw material for supplementing wood in meeting a cellulose shortage. The fact that straw has not been used in this country, excepting for paperboard manufacture, is based to a considerable extent on economic considerations. Straw is being used increasingly in Europe for paper manufacture under war conditions. One mill in England *(1)* which hitherto used wood pulp and esparto is now using 400 tons of straw per week, replacing all the esparto and part of the wood pulp.

Three important questions deserve answers in any reconsideration of cereal straws as a source for cellulose pulps, (a) availability, (b) quality, and (c) methods and costs of collection.

In 1940, before the Northern Regional Research Laboratory[3] was ready for occupancy, the authors began to put into effect the broad plans prepared by the Bureau of Agriculture Chemistry and Engineering for commercial development of agricultural residues by (a) making a survey of the present industrial uses and availability of straws, (b) by collection of authentic samples of straws from distinct varieties of wheat for complete physical and chemical analyses, and (c) by institution of cooperative studies with agricultural equipment manufacturers and state agricultural experiment stations to develop improved machines and methods for more economical collection of residues on the farm in a cleaner and more desirable commercial condition.

Availability and Distribution

The principal areas in which the cereal straws, wheat, rye, barley, and rice and flax straw are grown in considerable acreage and where the straw is not used entirely on the farm, as in the dairy districts of Wisconsin, are shown in Fig. 1. Oat straw is not discussed because it is more valuable than the other straws for feeding and bedding purposes and is not so suitable as a source of cellulose because of its high leaf content. An estimate is given in Table I of the tonnage of straw produced in the United States, the part of this available for use off the farm, and the tonnage used by industry. The estimated production of straw is based on the average production of grain. It is difficult to obtain a definite off-the-farm estimate for these straws, because, in addition to some large industrial uses, there are many local uses to which straw is put. These local uses support custom balers or baling machines used on the farm and widen the experience in straw collection and handling.

The largest industrial use of straw (6 to 7 hundred thousand tons), mainly wheat straw, is for the manufacture of corrugating strawboard. Because of unanticipated straw requirements, at least during the past two years, such straw has contained a certain amount of oat straw. Ordinarily strawboard manufacturers do not want oat straw, claiming that it gives an inferior product and a lower yield. Some strawboard mills will not accept more than a small percentage of oat straw and deduct for the amount present. Operators of straw paperboard mills state that rye straw is probably slightly superior to wheat straw for producing a stiff corrugating paperboard, while neither barley nor oat straw is desirable.

Attention should be called to the greatly increased use of seed-flax straw by the new and thriving American cigarette paper manufacturers. This use of a special fiber to produce a special result in papermaking, not produced by wood fibers, points to a logical use of other cereal straw fibers for cellulose purposes, namely, for specialty papers. The seed-flax straw, generally cut by a binder-harvester, shocked, threshed, and baled from the stack, must be shipped to tow mills to remove the woody portion or shive from the bast fiber or tow. The shive constitutes about 80%

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[3] The Northern Regional Research Laboratory is one of four regional laboratories authorized by Congress in the Agricultural Adjustment Act of 1938 for the purpose of conducting research to develop new uses and outlets for agricultural commodities. These laboratories are administered by the Bureau of Agricultural Chemistry and Engineering of the U. S. Department of Agriculture.

TABLE I.—CEREAL AND FLAX STRAWS[1]: THEIR PRODUCTION AND AVAILABILITY FOR INDUSTRIAL UTILIZATION

Kind	1941 Grain production, bushels	Straw to grain ratio[2]	Straw: Over-all production, tons	Straw: Portion which can be used advantageously on the farm[2], %	Straw: Portion available for use off-the-farm, tons	Estimated portion now used by industry, tons
Wheat	945,937,000	1.9:1	53,918,409	25	40,438,807	1,000,000[3]
Rye	45,191,000	2.5:1	3,163,370	25	2,372,528	
Barley	358,709,000	1.2:1	10,330,819	25	7,748,115	
Rice	54,028,000	[4]	1,561,679	25[5]	1,171,257	60,000
Flax	31,485,000	4:1	3,526,320[6]	..	2,821,956[6]	200,000
Totals	.....	....	72,500,597	..	54,551,763	1,260,000

[1] Oats straw is not included. It is more valuable for feed and bedding on the farm and less desirable for cellulose purposes.
[2] Data from U. S. Department of Agriculture processed report of October, 1935, entitled "Preliminary Estimates of Farm Products, By-Products, and Wastes Available for Industrial Use".
[3] Roughly estimated at seven hundred thousand tons used by the straw board industry, 50,000 tons in bighway construction and soil erosion prevention work, and 250,000 tons for packing, chicken litter, and off-the-farm bedding purposes.
[4] A ratio of 1.1:1 was used for California and Louisiana rice production and one of 1.5:1, for Arkansas and Texas production.
[5] Includes also inaccessible straw.
[6] Consisting of approximately 20% bast fiber and 80% shives.

and the tow 20% of the straw. The tow, which is the only portion used in cigarette papermaking, is baled and shipped to the eastern seaboard. The tow from fiber-flax processing may be used for cigarette paper manufacture. With increasing flaxseed production due to the war, larger tonnages of seed-flax straw will be available. Improvement of methods and lowering of costs of collection may be expected.

Many attempts have been made to utilize the flax shive, so far without any outstanding success. To this problem we are giving attention.

This past season there has been an increased industrial movement of rice straw, particularly into the insulating board industry.

It will be noted from Table I that while about one million tons of straws find an industrial outlet, mainly in the manufacture of cellulose products, many times as much is available. While the mulching methods of water and soil conservation which have recently been developed will undoubtedly widen the use for these cereal straws on the farm in some regions, we can confidently expect a tremendous potential raw material reservoir, annually replenished, of such cellulosic raw materials. With increased farm production consequent to war conditions these supplies will increase. England, Germany, Russia, and others of the war-ridden nations have turned to straw and other residues to assist them in their cellulose economy.

Physical and Chemical Properties of Straw

Thus far most of the chemical and physical studies on straw have been undertaken either from the standpoint of feeding or fertilizer value. Most of published analyses are of little value to the cellulose technologist. As a part of the broad program to develop commercial uses for agricultural residues, there is presented in Table II a physical analysis of the component parts of a number of outstanding varieties of wheat straw, barley straw, and rye straw. The physical examination not only of other straws, but of other crop residues, such as cornstalks, corncobs, etc., is under way at the Northern Regional Research Laboratory.

An examination of the data in Table II shows that there is considerable difference in physical make-up

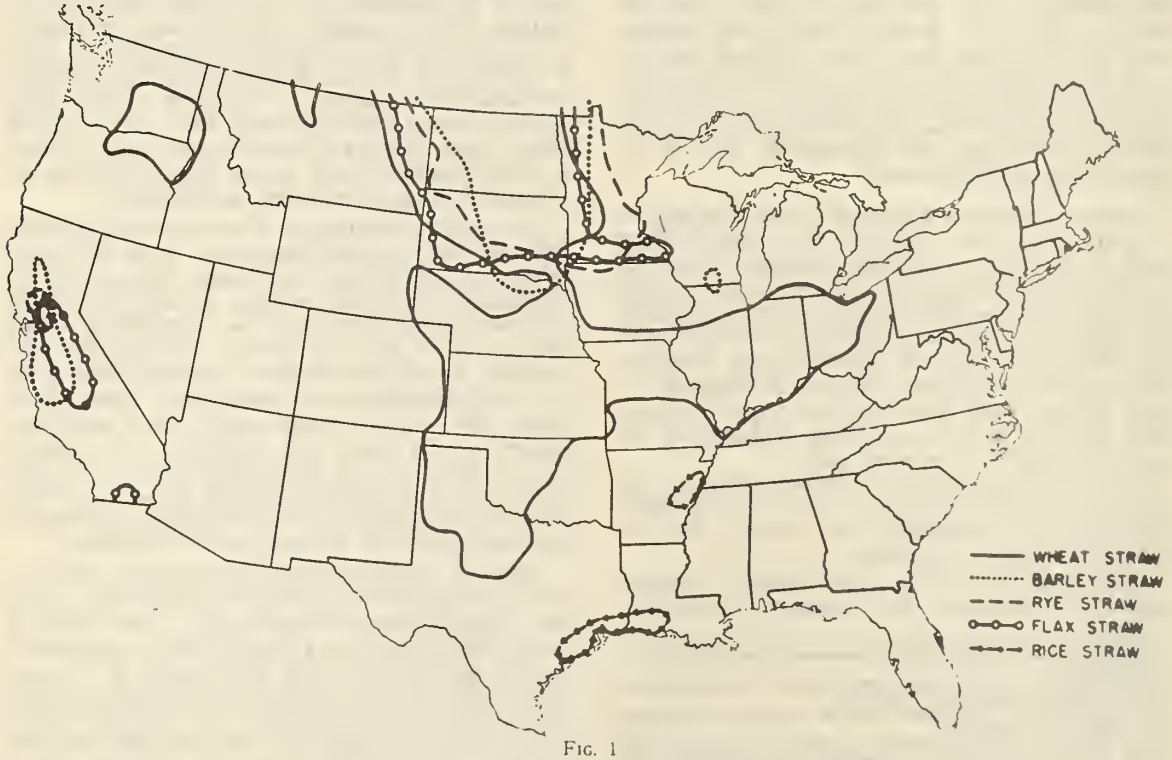

FIG. 1
Principal Areas in Which Cereal Straws Are Available Off the Farm

among the straw varieties. The most desirable part of the straw for cellulose manufacture is the stem. The least desirable portion is the chaff, with the leaf blade as a close second. There is a wide variation in the percentage of these three components among the wheat straw samples. Sweeping conclusions cannot be drawn from these data, but it is evident that this type of analysis will be important in locating the best sources of raw material. Rye straw is shown to have a larger percentage of stem and less blades than wheat or barley, which is in accord with the current belief that rye is superior to wheat for board manufacture.

In Table III is presented a comprehensive chemical analysis of the various component parts of straw Sample 11 of Table II. These data bring out very clearly the undesirable character of the chaff, with its high ash content, most of which is composed of silica, its relatively high water-solubility, high alkali-solubility, high nitrogen content, and its low holocellulose and alpha-cellulose contents. The leaf blades run a close second to chaff from the standpoint of undesirability for pulping purposes. In both the chaff and the leaf blades the fiber length is much smaller than in the stem. These parts of the plant have the least commercial value for pulping and complicate the pulping problem by their consumption of chemicals and by their low retention in the board or paper with consequent contribution of fine fiber to mill effluents. The composition of the stem indicates that it is by far the best cellulose source. The leaf sheath is so closely attached to the stem that no mechanical separation is practicable.

It will be noted that while the nodes are quite high in ash, they are low in silica. The higher ash content of the node as compared with the internode results in a lower alpha-cellulose or holocellulose content by the former. The chemical composition of wheat straw as shown by the data in Table III may vary in other straw varieties. As time permits, a series of commercial varieties of straw will be analyzed to determine their value as cellulose to industry, looking toward improvement in industrial quality by known methods of plant selection and genetics.

Effect of Method of Harvesting and Collection on Quality of Straw

Until recent years all industrial straw has been secured by baling from straw ricks or stacks, the straw having been harvested by the binder method which ordinarily leaves a stubble of four to six inches in the field. In threshing the grain, the chaff and fine material in the thresher is separated from the coarse straw, but in domestic threshing machines these fractions are recombined so that the farm-stack straw contains both coarse straw and chaff. Attachments are available, however, whereby the straw and chaff can be collected separately. European practice separates the chaff for use in stock feeding. It will be seen from the analyses given in Table III that the chaff and blades are both fairly high in nitrogen and in water-soluble material and, consequently, are of value as feeding material. As a rule material having food value also has fertilizer value.

In general, the straw paperboard mills have depended on custom balers to bale straw from the farm stack. An advantage in stack straw is that the straw can be baled on the farm during the off season when

TABLE II.—STRUCTURAL COMPOSITION OF MATURE UNTHRESHED WHEAT, RYE, AND BARLEY STRAW CUT BY HAND (GRAIN EXCLUDED)

Sample No.	Variety	Source	Stems (culms), %	Leaves: Blades, %	Leaves: Sheaths, %	Chaff[1], %	Approx. height of cutting, inches	Length of cut straw[3], inches
WHEAT STRAW								
1	Kawvale ...	Ill.	52.6	11.9	19.0	16.5	2.5	44.6
11	Russian (Hardy Northern)..	Ill.	54.6	11.4	18.1	15.9	2.5	38.7
4	Purkof	Ind.	54.6	10.6	18.2	16.6	2.5	38.7
67	Trumbull ..	Ohio	59.4	12.5	21.9	6.2	1	30.9
69	Fulhio	Ohio	54.8	10.4	20.5	14.3	1	44.8
78	Kharkof ...	Kan.	47.6	9.9	22.2	20.3	[2]	29.8
82	Tenmarq ...	Kan.	49.6	7.4	20.0	23.0	[2]	28.0
84	Blackhull ..	Kan.	50.6	8.1	23.5	17.8	[2]	29.8
401	Federation .	Wash.	38.3	7.1	21.1	33.5	6	18.7
403	Rex	Wash.	54.0	13.5	17.0	15.5	10	38.2
406	Baart	Wash.	44.1	4.9	19.1	31.9	6	26.7
	Average ..		50.9	9.8	20.1	19.2	...	35.4
BARLEY STRAW								
651	Missouri Early Beardless .	Mo.	55.7	12.2	26.4	5.7	[2]	32.0
914	Wisconsin Pedigree 38	Wis.	47.9	10.6	23.2	18.3	[2]	29.4
916	Peatland ...	Wis.	52.9	10.9	22.5	13.7	[2]	30.9
	Average ..		52.2	11.2	24.0	12.6	...	30.7
RYE STRAW								
386	Rosen	Mich.	62.3	5.3	18.8	13.6	3.5	53.2

[1] Chaff includes threshed heads (rachises), hulls (glumes), beards (awns), and small pieces of stems and leaves.
[2] Not available but probably 2 to 2.5 inches.
[3] Average of 50 plants selected at random from each sample.

TABLE III.—CHEMICAL ANALYSIS OF COMPONENTS OF WHEAT STRAW
(Percentage by weight, moisture-free basis)

Component	Production of whole straw, %	Ash, %	Silica, %	Hot water soluble, %	1% NaOH soluble, %	Alcohol-Benzene soluble, %	Pentosans, %	Lignin ash-free, %	Nitrogen, %	C and B, cellulose ash-free, %	Holocellulose ash-free, %	Alpha-cellulose ash-free (from holo), %	Methoxyl, %
Straw [1]	100.00	7.43	5.33	11.7	44.0	7.2	29.4	14.2	0.34	54.5	68.8	40.7	3.13
Stems (culms) [2]:	54.65	3.91	2.24	9.1	38.6	6.8	29.5	16.7	0.22	57.2	73.4	43.9	3.88
1st (top) internodes	3.80	4.06	2.51	12.2	43.2	8.7	29.7	15.3	0.35	54.6	70.3	39.7	3.54
2nd internodes	10.86	3.43	1.97	7.7	37.5	5.8	29.7	17.1	0.16	58.7	75.7	45.6	3.97
3rd internodes	17.17	3.55	2.46	5.9	34.3	4.9	29.2	17.5	0.10	60.8	75.4	47.4	4.08
4th internodes	16.08	3.63	2.62	5.9	33.0	5.2	30.0	17.8	0.10	60.4	75.6	48.2	4.26
Internodes, unclassified	3.05	Assumed similar in composition to other internodes											
Nodes	3.69	7.60	1.11	15.7	42.5	8.2	30.6	17.1	0.38	46.0	68.4	39.9	4.07
Blades	11.39	10.28	7.38	18.8	53.1	10.2	23.4	9.6	0.93	49.0	59.0	36.0	1.59
Sheaths	18.05	9.08	5.77	14.0	47.9	7.0	31.8	12.6	0.26	53.2	66.1	38.8	2.66
Chaff [2]:	15.91	15.62	14.01	12.8	51.9	6.9	30.9	10.7	0.41	50.7	63.3	35.4	2.22
Beards (awns)	4.22	19.65	18.46	11.7	53.0	6.8	29.2	7.8	0.33	53.6	63.9	37.1	1.58
Hulls (glumes)	9.25	16.44	14.83	13.8	52.1	6.8	30.5	11.0	0.43	48.0	60.7	33.1	2.23
Unthreshed heads (rachises)	2.44	5.57	3.23	10.9	49.4	7.6	35.4	14.9	0.50	56.0	72.4	41.0	3.29

[1] Whole straw, Sample No. 11, Russian (Hardy Northern) variety from Patterson farm, Hanna City, Illinois, cut by hand before threshing. Cut about 2.5 inches above the ground.
[2] Calculated from parts.

there is not so much demand on farm labor for more important work. The moisture content, particularly of straw baled from the farm stack during the wet winter months, is a most variable quantity. While experienced straw buyers can judge fairly well the quantity of water in baled straw and make weight deductions accordingly, this item of variable moisture content of straw is one of the most serious obstacles in obtaining chemical control during the cooking operation. Storage in the farm stack causes an uncontrollable amount of change in the straw due to weathering; therefore, when the matter of quality, is left in the hands of the custom baler, whose object is naturally one of maximum profit, close control of quality, such as is obtained in many parts of the wood pulp industry, cannot be attained. Due to fire hazards straw paperboard mills do not like to store more baled straw on their property than is necessary to maintain supplies to insure continuous operation.

With the advent of power machinery on the farm the methods of harvesting cereal grains have undergone profound changes. The use of the combine harvester started first on the Pacific coast and has steadily moved eastward. On the west coast there is little use for straw either on or off the farm, and the combine harvester, therefore, has been operated on the plan of merely heading the grain and spreading the straw and chaff over the stubble. As smaller acreages began to be encountered in the eastern wheat growing states, farm equipment manufacturers successfully built smaller, lighter, and lower-cost combine harvesters which, not only successfully harvested cereal grain, but also such diverse crops as soybeans, alfalfa, clover, flax, millet, and vegetable garden seeds.The utility of these machines has therefore become much greater than that of the binder harvester.

A few years ago certain operators of straw paperboard mills became fearful of insufficient straw procurement with this change in agricultural practice and endeavored to interest some of the farm-equipment companies in the development of pick-up baling machinery for the economic collection of straw on those farms where the combine harvester was being used. Such little interest was shown at that time, due to the small number of balers required, that a group of the straw paperboard companies themselves undertook and have succeeded in the development of a good pick-up baler; this is now being marketed. The interest of the farm-equipment industry has since become active in the development and manufacture of suitable light pick-up baling machinery.

In our survey, many mills were found opposed to the use of combine harvested straw. Western mills were most friendly to its use and the eastern mills least friendly. This was due to the fact that the advent of the combine in Ohio followed by some years its entry into Illinois and Indiana and, therefore, less attention to the quality of the straw and to the methods of collection had been given in the more easterly states. Certain mills claimed that the effects of sun and rain on the combine straw left in the field for a week or so before mowing the stubble and baling caused it to be sunburned, deteriorated by molding, more brittle, and of general lower quality than normal farm-stack straw. Some mills believed properly secured combine straw to be superior to farm-stack straw. There seemed to be no good way to answer these questions except by direct experimental procedure. Consequently, two farms in the vicinity of Peoria, Ill., and a farm in the vicinity of some of the large straw paperboard mills in western Indiana were selected as areas to collect combine straw samples undergoing weathering changes.

In using the combine harvester it is possible to mow the grain at different heights from the ground. Naturally with the longer stem the percentage of chaff and heads lessens. In a recent symposium on straw collection, methods, and costs, Mayer *(2)* presented data given in Table IV, showing the percentage of straw collectable and available when cut at different heights of stubble. As will be shown, it is practicable, at least under certain conditions, with the use of the combine harvester to cut to a stubble of six inches. This is possibly as low as the straw should be cut to keep it comparatively free from dirt.

Table V shows the physical analysis of straw samples in relation to the effects of weathering. Because of the large number of chemical determinations necessary, only one sample of combine straw, (Sample 11, Table II) collected on the Patterson farm, Hanna City, Ill., was analyzed chemically after different pe-

TABLE IV.—PROPORTION OF WHEAT STRAW AVAILABLE WHEN CUT AT DIFFERENT HEIGHTS OF STUBBLE [1]

Stubble height, inches	Field 1 %	Field 2 %	Field 3 %
0	100.0	100.0	100.0
6	71.6	79.5	79.5
8	65.8	71.8	71.7
10	58.6	64.8	64.5
12	51.2	57.8	57.2
14	45.2	51.3	50.6
16	39.2	44.7	44.2
18	33.8	39.7	38.6
20	28.0	34.7	33.6
22	23.6	29.2	28.6
24	19.6	24.6	23.6

[1] Data by I. D. Mayer, Purdue University, Lafayette, Indiana.
Note: Height of straw ranged from approximately 20 to 42 inches.

TABLE V.—EFFECT OF THE LENGTH OF TIME LEFT IN FIELD [1] AFTER HARVEST ON THE PERCENTAGE AND PHYSICAL CONDITION OF THE STEMS, LEAF BLADES, AND LEAF SHEATHS IN WHEAT STRAW
(Percentages based on straw as cut including chaff and unthreashed grain)

Sample	No. of days left in field	Stems %	Stems Condition [2]	Leaf Blades %	Leaf Blades Condition [2]	Leaf Sheaths %	Leaf Sheaths Condition [2]
COMBINE STRAW							
Purkof Variety—Woodward farm, Farmersburg, Indiana							
5	0	61.6	BC	8.3	SW	15.1	BC
17	10	57.2	BC	10.3	MW	18.9	SW
22	15	57.0	SW	9.3	BW	18.5	MW
Russian (Hardy Northern) Variety—Patterson farm, Hanna City, Illinois							
12	0	61.0	BC	8.8	SW	14.9	BC
20	12	69.1	BC	9.0	BW	13.9	SW
23	26	69.4	SW	7.1	BW	16.1	MW
30	36	68.8	SW	7.2	BW	15.2	MW
Kawvale Variety—McDonald farm, Hanna City, Illinois							
2	0	66.5	BC	6.2	SW	16.6	BC
9	3	56.8	BC	8.4	SW	19.8	BC
18	15	67.8	BC	7.8	MW	16.1	SW
STUBBLE STRAW							
Purkof Variety—Woodward farm, Farmersburg, Indiana							
6	0	65.5	BC	11.3	SW	21.4	BC
Russian (Hardy Northern) Variety—Patterson farm, Hanna City, Illinois							
13	0	65.8	BC	11.8	SW	20.0	BC
21	12	67.0	BC	11.4	SW	20.5	BC
24	26	70.0	SW	8.0	MW	21.4	SW
31	36	71.6	SW	6.8	BW	21.2	MW
Kawvale Variety—McDonald farm, Hanna City, Illinois							
3	0	64.7	BC	11.2	SW	21.7	BC
10	3	64.0	BC	11.3	SW	22.5	BC
19	15	65.6	BC	10.5	MW	23.0	SW
25	29	72.7	SW	4.1	BW	22.5	MW

[1] Rainfall occurring during time straw was left in field:
Purkof variety, Woodward farm—heavy rain 2 days after harvest, light rains 6, 12, and 13 days after harvest.
Russian (Hardy Northern) variety, Patterson farm—½ inch of rain 20 days after harvest, ¼ inch of rain 21 days after harvest, and ¼ inch of rain 25 days after harvest.
Kawvale variety, McDonald farm—½ inch of rain 23 days after harvest, ¼ inch of rain 24 days after harvest, and ¼ inch of rain 28 days after harvest.

[2] Explanation of symbols used in denoting condition as affected by weathering:
BC—Bright and clean
SW—Slightly weathered
MW—Moderately weathered
BW—Badly weathered

TABLE VI.—EFFECT OF LENGTH OF TIME LEFT IN FIELD AFTER HARVEST ON THE PHYSICAL PROPERTIES AND CHEMICAL COMPOSITION OF COMBINE STRAW [1]

		Physical Properties		Chemical Analysis										
Sample	Component and days left in field	Portion of whole straw, %	Condition [3]	Ash, %	Silica, %	Hot water soluble, %	1% NaOH soluble, %	Alcohol-benzene soluble, %	Pentosans, %	Lignin ash-free, %	Nitrogen, %	C and B cellulose ash-free, %	Holo-cellulose ash-free, %	Alpha-cellulose ash-free (from holo), %
	Whole straw [2]													
20	12	100.0	...	6.06	3.49	10.7	41.7	5.6	28.1	16.2	.45	53.7	69.7	44.1
23	26	100.0	...	5.08	3.41	8.4	42.4	3.2	29.5	16.5	.36	55.3	69.5	43.5
30	36	100.0	...	5.51	4.11	7.2	40.1	3.2	28.2	16.5	.37	55.6	67.9	43.3
	Stems													
20	12	69.6	BC	4.56	2.29	8.8	38.7	5.2	28.3	17.5	.30	55.1	72.1	46.2
23	26	70.0	SW	3.37	2.04	6.7	37.7	2.5	30.0	17.9	.24	56.4	71.4	45.1
30	36	69.3	SW	3.77	2.65	5.5	37.0	2.4	28.3	17.8	.24	56.8	69.5	45.0
	Blades													
20	12	9.1	BW	10.66	6.82	19.2	52.3	8.9	21.3	11.1	1.29	49.5	59.3	37.4
23	26	7.2	BW	11.12	8.01	17.9	51.0	8.8	19.9	11.0	1.19	48.7	55.5	34.5
30	36	7.3	BW	12.42	9.40	14.3	51.4	8.5	19.5	12.7	1.19	47.6	57.2	35.0
	Sheaths													
20	12	14.0	SW	9.18	5.94	13.4	47.5	4.7	30.6	14.0	.51	50.4	67.4	40.4
23	26	16.2	MW	8.46	6.33	10.6	56.9	3.8	31.4	13.8	.37	53.8	68.6	41.2
30	36	15.3	MW	8.53	6.80	10.1	45.3	3.3	31.3	13.9	.40	54.3	66.0	41.1

[1] Russian (Hardy Northern) variety from Patterson farm, Hanna City, Illinois.
[2] Computed from analysis of components.
[3] Explanation of symbols used in denoting condition as affected by weathering: {BC —Bright and clean SW—Slightly weathered MW—Moderately weathered BW—Badly weathered

riods of weathering, as shown in Table VI. One-half inch of rain fell 20 days after the harvest; one-fourth inch 21 days after; and one-fourth inch 25 days after. In Table VII a similar analysis of stubble straw is given, it having been suggested by some of the mills that when rain collected in the open ends of the stubble decomposition in the cut-internode took place. An examination of these three tables indicates that there was little physical loss of material except in the leaf blades; this was borne out by the visual signs of weathering and by the chemical analyses.

Referring to the chemical analyses it is to be noted that losses took place particularly in the hot water-soluble and alcohol-benzene-soluble portions of practically all parts of the combine straw and the stubble. In general, there was a loss in nitrogen. Changes in the more important constituents, such as alpha-cellulose, holocellulose, and lignin, appear to be rather slight or negligible. Any losses that have resulted in the leaf blades probably are beneficial rather than otherwise from the standpoint of using straw as a raw material source of cellulose. From this study it is evident that no serious damage has taken place under these conditions in the straw during a period of 36 days' exposure to the elements. Satisfactory pulp has been prepared from this straw in the laboratory pilot plant.

It is obvious that fields containing large amounts of weeds, particularly green weeds, are not suitable for producing straw for cellulose. Experience has shown that straw left by a combine should be collected promptly enough after harvesting so that weed growth in the stubble to be cut does not seriously contaminate the straw. Such weeds respond to other than optimum cooking conditions for straw and when baled green act as focal points for decomposition and heating in the bale.

Methods and Costs of Collection

Straw Costs to Mill

In normal times, straw in 70- to 80-pound bales f.o.b. mill varies in cost from $5.00 to $7.50 per ton, depending on a variety of local conditions. In 1940, when the war situation dried up pulp imports, unanticipated straw demands brought mill costs for winter and spring straw to $8.00 or $8.50 a ton. A delivered price of about $6.00 per ton for farm-stack straw is said to assure profitable operation in an efficient mill in normal times.

Practically all straw is purchased from custom balers and only in a few cases do mills deal directly with farmers. Mills dealing directly with farmers do so because they are trying to pay the farmer a better price, or to assure the farmer of payment for the straw, so as to secure a sustained supply. Some custom balers are said, because of financial instability, to have failed to live up to their contracts with farmers. While collection of straw by custom balers may be the most practical collection channel, financial transactions between the farmer and the mill would

TABLE VII.—EFFECT OF LENGTH OF TIME LEFT IN FIELD AFTER HARVEST ON THE PHYSICAL PROPERTIES AND CHEMICAL COMPOSITION OF STUBBLE STRAW [1]

		Physical Properties		Chemical Analysis										
Sample	Component and days left in field	Portion of whole straw, %	Condition [3]	Ash, %	Silica, %	Hot water soluble, %	1% NaOH soluble, %	Alcohol-benzene soluble, %	Pentosans, %	Lignin ash-free, %	Nitrogen, %	C and B cellulose ash-free, %	Holo-cellulose ash-free, %	Alpha-cellulose ash-free (from holo), %
	Whole straw [2]													
21	12	100.00	...	5.90	4.03	8.4	39.0	5.2	28.9	16.8	.25	54.8	71.1	47.3
24	26	100.00	...	5.71	4.15	7.0	37.7	3.3	28.7	16.6	.20	56.2	68.9	45.1
31	36	100.00	...	5.41	4.09	6.7	37.6	3.2	28.2	16.7	.20	56.3	68.2	44.1
	Stems													
21	12	67.17	BC	4.04	2.49	6.2	33.7	5.2	28.4	19.1	.14	56.0	73.7	50.2
24	26	70.03	SW	4.14	2.71	5.5	33.4	2.8	28.6	18.5	.13	57.9	70.7	46.9
31	36	71.65	SW	3.68	2.55	5.2	33.4	2.8	28.0	18.8	.13	58.0	70.3	46.0
	Blades													
21	12	11.43	SW	11.92	9.00	16.3	54.6	8.1	24.3	10.3	.91	54.3	65.5	42.5
24	26	8.06	MW	11.38	9.16	11.2	49.0	7.3	21.4	9.4	.75	55.1	61.6	40.8
31	36	6.75	BW	12.80	10.49	11.6	50.7	7.0	20.5	9.2	.72	50.3	59.8	36.6
	Sheatbs													
21	12	20.58	BC	8.57	6.20	11.0	47.4	3.9	32.8	13.2	.26	51.6	66.2	40.9
24	26	21.43	SW	8.65	6.90	10.3	47.7	3.4	32.1	12.6	.25	52.0	66.0	40.9
31	36	21.20	MW	8.81	7.19	10.5	47.8	3.5	31.1	12.0	.27	52.6	64.7	40.3

[1] Russian (Hardy Northern) variety from Patterson farm, Hanna City, Illinois.
[2] Computed from analysis of components.
[3] Explanation of symbols used in denoting condition as affected by weathering: {BC —Bright and clean SW—Slightly weathered MW—Moderately weathered BW—Badly weathered

appear to be a sound step in assuring stability of sustained straw supply sources.

Straw Prices to Farmer

The farmer normally receives from $0.75 to $1.00 or slightly more per ton for straw in the farm stack or as standing stubble, depending on local conditions. This return is evidently too low to interest the farmer to any large extent. Due to competition between straw paperboard and kraft paper in the corrugating paperboard market, the former cannot afford to pay increased prices for straw. It is evident that if the farmer is to obtain a greater return, it must result from improved and lower-cost methods of collection and lower transportation costs. Recent developments show progress in this direction and improvements in straw quality as well.

Transportation Costs

During the past ten or twelve years the radius from which mills have gathered straw has approximately doubled, owing to a decrease in straw availability. There are probably three reasons for this decrease in straw availability: (a) restricted acreage under government control of wheat production and soil conservation measures; (b) failures of farmers to receive sufficient return for farm-stack straw to keep them much interested in this industrial outlet; and (c) the advent of the combine harvester, particularly the small combine, in the states of Ohio, Indiana, Illinois, and Iowa.

Transportation of straw from the farm to the mill by truck is the general method. This permits delivery direct to the mill stack and eliminates one hauling operation as compared with railroad transportation—*viz.*, hauling from the railroad car to the storage pile. In 1940, average trucking charges were $2.50 a ton; some mills with short hauls paid as little as $1.00 and others unfavorably located paid as high as $4.00. This high hauling charge in perhaps most areas could be reduced if farmers nearer the mill could be more interested in supplying straw. The mill operator without paying more for delivered straw would gain in stability of operation by finding a way, let us say, to pay the farmers $1.00 more per ton of straw in that radius of $1.50 transportation cost. This situation could be brought about by inaugurating an aggressive campaign on the part of the mill to increase financial business relations between the farmers and the mill. The custom baler channel could still be maintained by contracting with the custom baler to collect straw at a fixed price from farms on which the mill has contracted straw purchases. There is a possibility that farmers' cooperative associations would undertake custom baling. Such a move would place the purchase price to the farmer for stack or stubble straw in the hands of the straw paperboard mill rather than as is general now, in the hands of the custom baler.

Baling Costs

The cost of baling from the farmers' stack by the stationary baler was found to average about $2.00 a ton, to which must be added about $0.50 a ton profit to the custom baler. If straw is trucked to railroad cars, a loading charge of about $0.50 a ton must be added. These prices vary somewhat according to local conditions. With the advent of the combine harvester some years ago it was found that baling costs in general increased due to the heavy type of pick-up baler then in use and to lack of experience in the best way to conduct the new operations in collecting scattered straw and stubble in the field. To obtain a good yield of straw this stubble had to be mowed.

With the new emphasis placed on the possibility of industrial use of agricultural residues by the establishment of the Northern Regional Research Laboratory, the American Society of Agricultural Engineers, many members of which are engaged in the farm-equipment industry, became greatly interested in the collection problem since it was evident that high collection costs were a bottleneck and new methods of collection and new machines would have to be designed to meet the changing conditions. It became evident that unless some simple, low-cost means were found for the farmer to collect combine straw for use on his own farm, the sale of the small combine would be slowed up. The requirements for farm straw, as will be observed in Table I, are higher than the present commercial outlets for straw. Thus farm use alone justifies production of lightweight baling equipment. At the same time the demand for improved methods in hay making gave an impetus to the development of pick-up balers for this crop. As a result of the three recent symposia held before the American Society of Agricultural Engineers and of cooperative work with farm equipment manufacturers, definite progress in improving collection methods and in lowering collection costs can be reported.

An analysis of the problem indicated that all unnecessary steps in harvesting the grain and in collecting straw must be eliminated and that labor must be reduced to a minimum. Deterioration of baled straw

TABLE VIII.—COST OF BALING COMBINE STRAW WITH PICK-UP BALERS—USING VARIOUS METHODS OF CUTTING AND WINDROWING

Method and Identification	Costs per ton of baling							
	Baler	Tractor	Wire or twine	Labor (baling)	Raking with side delivery rake, man and team	Windrower	Mower	Total
Minnesota Costs [1]								
Average several tests on farms with different outfits and different methods	$ .407	$ .229	$ .401	$ .531	$	$	$	$1.57
LaFayette, Indiana test [2]								
High cutting (12"). 3 swaths raked together with side delivery rake ...	.351	.163	.490	.466	.713	....	....	2.09
Springfield, Illinois tests [3]								
High cutting (16"). Stubble mowed, windrowed and baled in one operation	.395	.313	.450	.645	....	.008	.186	2.00
Low cutting (6"). Single windrow left by combine without straw spreader..	.370	.163	.450	.450	....	....	....	1.43
Low cutting (6"). Double windrow made by windrower attached to combine	.351	.127	.450	.321	....	.001	....	1.25

[1] Baling Straw with the Pick-up Baler. By A. J. Schwantes (University of Minnesota). Paper presented at fall meeting of American Society of Agricultural Engineers. 1941.

[2] Based on data obtained from "Straw Collection after Combining" by I. D. Mayer (Purdue University). Paper presented at fall meeting of American Society of Agricultural Engineers. 1941.

[3] Based on data obtained from "Baling Straw from Windrow Left by Combine" by A. L. Young (University of Illinois). Paper presented at fall meeting of American Society of Agricultural Engineers. 1941.

can be eliminated by keeping it dry. It follows, therefore, that straw baled in the driest condition has the best chance for maintaining quality. Since it is necessary to have the grain dry at the time of combining, straw then is in its driest condition for baling. If some time is allowed to elapse before the stubble is cut, weeds or clover grow in the field and a poor grade of straw is likely to result. Furthermore, in fields where clover follows the grain crop, a better stand and quality of first-cut clover hay is obtained if the stubble is cut as soon as possible after combining.

The following consecutive operations are often used in harvesting grain and collecting straw: (a) combining, leaving a high stubble, (b) cutting the stubble with a power mower, (c) double windrowing of the combine straw and cut stubble, and (d) picking up the windrows with a pick-up baler.

During the past two or three years experimental studies on various combinations of machines to eliminate unnecessary steps in field baling of combine straw have been conducted. Furthermore, there have been new developments in lower-cost, much lighter, pick-up balers. In Table VIII is given a resume of results of such tests, presented at a symposium of the American Society of Agricultural Engineers in December, 1941. Table IX gives the basis of calculation of fixed cost of farm implements used in the tests so that the various cost estimates may be brought into line. Referring to the Springfield test, cited in Table VIII, a low collecting cost of $1.25 per ton of baled straw in which only two operating machines were used, is shown. In this test a small combine harvested the wheat, cut a low stubble of six inches, and formed the straw into double windrows. Following this combine was a pick-up baler to which was attached a small trailer dump cart. Comparing this procedure with the one of four operations described above, it will be seen that the power mower and the windrower, as well as the cost of operating these machines, were eliminated. (*See* Fig. 2.)

FIG. 2
Combine, Pickup Baler and Trailer Dump Carts Used in Springfield Tests. Note Short Stubble and Double Windrow

TABLE X.—CHAFF CONTENT OF WHEAT STRAW AS REPORTED FROM VARIOUS SOURCES

Harvesting and collection method used	Description of straw or source of information	Chaff content [1] %
Binder-harvested baled stack straw	European observation	18.0
	Mill "A," Indiana, 1940 (sample representing 24-hour run)—Strawboard Mill analysis	18.6
	Mill "B," Indiana, 1940 (sample representing 24-hour run)—Strawboard Mill analysis	18.3
	Baled in Iowa	17.3
Cut and threshed by hand	Average of 11 varieties (Table II)	19.2
Combine-harvested baled with pick-up baler	Springfield, Ill., straw collection tests:	
	Single windrow operation	2.5
	Double windrow operation	3.5
	Indiana Mill "B" estimate (This mill uses large tonnage of combine straw)	5.0

[1] Material passing through 4 x 4 mesh wire sieve except in the case of the chaff content representing the average of 11 varieties which latter were hand separated.

More recent developments in light-weight pick-up balers show even greater promise of lower costs.

In describing a new pick-up baler which has gone through the engineering-development stage, Silver *(3)* states that with this machine, "The windrow is now to be rolled up, similar to the rolling up of a carpet, tied with twine when a 70-pound roll is secured and dropped at the rear of the machine either on to the ground or on to a wagon. This is a new principle fully automatic and is a good example of correct placement of the functional units . . . " The bales made by it are compact and would appear to lead to an improvement in compactness of piles, in ease of transportation, and in ability to shed water and thus withstand weathering. The baler is operated by one man and can be used as a stationary, as well as a pick-up, baler. Considering that these developments in machines have taken place in less than five years, it can confidently be expected that it will be possible to lower baling costs of straw in the near future to $1.50 or less per ton, including profit to the custom baler, as compared to the present average cost of $2.50 per ton, thus making possible a saving of at least $1.00 per ton in baling costs.

Chaff Content and Costs

It is generally agreed that chaff, heads, and leaf blades are of the least value in preparing pulp, not only because of high ash content and high solubilities, but also because the fibers in these parts of the plant are short. Many paperboard mill operators agree that these parts of the straw act mainly to use up chemicals and in considerable part appear in the mill effluent and thus contribute to stream pollution, an important problem to the mills. Some mills do not consider chaff to be a loss because of save-all systems. However, in the manufacture of fine papers from straw these parts would be a real liability.

No reliable information seemed available in the industry concerning the chaff content of baled farm-stack straw. Two large operators undertook analyses to determine chaff content and both found it to be

TABLE IX.—BASIS FOR CALCULATION OF FIXED COSTS ON FARM IMPLEMENTS USED IN TESTS [1]

Equipment used	Estimated use per year	Yearly depreciation	Yearly interest on investment	Yearly repairs	Yearly insurance, taxes, shelter
Baler	500 tons per year	10% of cost	5% of ½ cost	2% of cost	$10.00
Tractor	600 hours per year	10% of cost	5% of ½ cost	2½% of cost	$10.00
Mower	100 hours per year	10% of cost	5% of ½ cost	5% of cost	$1.50
Rake	100 hours per year	10% of cost	5% of ½ cost	5% of cost	$1.50

[1] Based on data obtained from "Baling Straw from Windrow Left by Combine," by A. L. Young (University of Illinois). Paper presented at fall meeting of American Society of Agricultural Engineers. 1941.

approximately 18%. The combine method of harvesting makes possible a low chaff content of straw and this low content can be further reduced by the use of an inexpensive attachment to the combine.

In Table X, data on the chaff content of commercial farm-stack and combine baled straw are given. These data show a reduction of chaff in combine straw as compared to stack straw amounting to 14% of the straw. Thus, when farm-stack straw costs $6.00 per ton, its chaff content represents about $1.00. If to this $1.00 cost is added operating overhead, costs of chemicals and steam for cooking, pumping, and processing charges for the fine fibers which leave the mill in the white water, probably another $1.00 or more of cost is involved. It is evident, therefore, that the use of combine straw, clean and low in chaff content, can bring to the mill considerably more than $1.00 a ton saving as compared to stack straw. Furthermore, the chaff, because of its fine condition and its higher nitrogen content, has more value to the farmer as a fertilizer than the other parts of combine straw and should probably go back to the land.

Increased Profit to Mill and to Farmer

Let us see how the improvements in straw quality and collection discussed can at the same time improve the economic condition of the farmer and the mill. Low-chaff content, combine straw has $1.00 per ton more fiber value than farm-stack straw, assuming a $6.00 per ton delivered price for straw.

If farmers within an average $1.50 per ton hauling radius (in preference to those supplying stack straw from the present average $2.50 radius) were paid $1.00 more for unbaled combine straw or stubble, then the delivered price to the mill would still be $6.00 per ton since the extra $1.00 paid the farmer is saved in hauling charges, which are a part of the f.o.b. price. Thus the farmer and the mill would each receive $1.00 per ton more from the increased value of combine straw. The farmer would probably not deliver less straw per acre than would be obtained from stack straw, taking into account actual losses in storing and baling stack straw. The mill would profit even more than the farmer due to lowered operating costs and improved yields with combine straw. This still leaves $1.00 per ton which may be saved in lowered baling costs. By a community of interest this saving, let us say, might be split between the mill and the farmer. Table XI shows how this works out.

TABLE XI.—COST COMPARISONS PER TON F.O.B. MILL FOR STRAW CONTAINING REGULAR CHAFF (FARM-STACK) VS. STRAW CONTAINING LOW CHAFF (COMBINE) AND BENEFITS TO FARMER AND MILL

	Farm-Stack Straw				
Items of cost	Regular content of chaff	Calculated to low chaff combine basis	Combine straw, low chaff content in $1.50 radius	Benefits	
Straw	$1.00	$1.16	$2.50	To farmer	$1.50
Baling	2.50	2.92	1.50		
Hauling	2.50	2.92	1.50		
Cost to mill	$6.00	$7.00	$5.50	To mill	$1.50

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